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The Relation of Plant Protoplasm to its Environment

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BY

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Dr. [illegible]
With the author's kind regards

1756

PHILADELPHIA
1912

PA Dept of Conservation and Natural Resources

THE RELATION OF PLANT PROTOPLASM TO ITS ENVIRONMENT.

By John Muirhead Macfarlane, D.Sc.

In discussions regarding the origin and the relations of plant and animal cells to their environment, we too often select and speak of the more highly organized groups of plants and animals, or of these when in the actively vegetating and reproductive phases. And so we treat of cells that consist of the more generalized substance *protoplasm* alongside the more specialized substance *nuclear chromatin,* while we ordinarily study both in their most active state.

But alike for the primitive origin of plants and animals, their means of dissemination and perpetuation, as well as their relation to higher forms, it is of prime importance that we should try to get exact conceptions as to the most primitive and most simple organisms, as well as the endurance capacity of the highest types now living.

The aim of this paper is to record observations, and to bring together results, that may aid us in our estimation of the life capacities of plant protoplasm. The writer has also brought together results, which he hopes to publish in time, bearing on animal protoplasm, and which show that between both there is a fundamental agreement.

While we would by no means consider that protoplasm is so simple a substance that it can, or probably will, be generated by the physiological chemist, on a few minutes' or a few hours' notice, we would equally consider that all experimental evidence indicates that it primitively originated by slow natural processes, at a stage in the world's history, when physico-chemical surroundings had become such as to favor actions and reactions that gradually resulted in its formation.

It becomes then a matter of high value to ascertain whether evidence can now be secured, that would aid us toward a solution of its mode of origin. In such an inquiry also, it will readily be conceded that the four great environmental factors which determine synthetic and analytic activities are temperature, light, electro-chemical action and water supply. Further if living organisms are to aid us in our interpretation of past existence, our studies should begin with those simplest forms that consist of non-nucleate protoplasm. In attempting to follow out such a line of inquiry, some biologists have emphasized the importance of types like the Myxomycetes and the Lobosa, as being irregular protoplasmic aggregations which ingest food, often in a solid state. But apart from the beautiful nuclei and nucleoli that these show, as well as the karyokinetic phases exhibited in their cell division, we would regard their mode of food absorption as a specialized—not a primitive—one. Even did we know more accurately regarding such forms as *Chlamydomyxa* amongst plants, and *Proto-*

myxa amongst animals, we are unable to view these as surviving remnants of primitive types.

At this stage then we would suggest that far too little emphasis has been placed on, and too little experiment has been conducted to extend, the value of Traube's discoveries regarding colloid membranes and their enclosures. Here we believe exists a wide field for study, in which the physico-chemist and the physiologist might join their experimental and observational efforts with happiest results.

Let us turn our attention now to that still fairly large group of organisms the Schizophyceæ, Protophyceæ, Cyanophyceæ or blue-green algæ. The writer's more minute attention was directed to them when his deceased student and colleague, Dr. O. P. Phillips, carried on careful and extended observations, that have already been published (1). Since then he has advanced his knowledge of them along various lines.

Though synonymy and a tendency to variation, or possibly to pleomorphism, have given rise to a copious nomenclature, we are probably justified in considering the group to be made up of about 80 genera and close on 650 species. Of these 518 species are freshwater or terrestrial, 21 are brackish water, and 111 are salt-water or found in saline lakes. It should further be noted that not a few of the species exhibit an environmental adaptability to fresh and brackish, or to brackish and salt water, or even to the first and last that is in marked contrast to the behavior of most of the higher plants. We would interpret such distributional features as an indication that the group originated in, and still largely adheres to, a freshwater life, though as we shall presently indicate, the term "freshwater" requires to be liberally interpreted.

In form they vary from simple spherical cells that are embedded in abundant mucilaginous sheaths or layers, like *Glœocapsa* and *Aphanocapsa*, to others like *Nostoc* that form connected threads of subspherical or oval cells embedded in mucilage, and again to types like *Oscillatoria* and *Rivularia* that are elongate usually branching filaments, enclosed in rather thin gelatinous walls, and made up of similar or dissimilar cells. In the color of the cell contents the above form-groups may vary from yellow to brownish-yellow, reddish or purplish-brown, red-green, purple-green or blue-green, more rarely a rich olive-green. Fairly well correlated with advance in color and in general morphology, a similar progress is shown in cytological detail. In simpler types like *Glœocapsa* and *Aphanocapsa*, the cell-contents consist only of an outer colored zone of very finely granular protoplasm, which holds the pigment above noted, and which has been termed the chromatophore. Within this is a more coarsely granular mass, which under high magnification suggests the existence of a finely reticular substance, that carries definite bodies of varying size and refraction.

As we advance through Nostocaceous types, the main difference is that reserve substances—chiefly glycogen—are not unfrequently stored in each cell, but more importantly we note that definite refractive granules, which absorb

chromatin stains, become more and more prominent, though irregularly and often widely scattered through the cell. In the higher thread forms like *Oscillatoria* and *Lyngbya* these granules are united into loosely coiled granular threads of chromatin, which we regard as a primitive and evolving nuclear structure.

The geographical distribution of the genera and species is noteworthy, for it is safe to say that in no other group—except possibly the mosses and to a less extent the ferns, both with small light spores—are so many species included that show an extended, often even a world-wide distribution. It is rare indeed, also, amongst higher or nucleate plants, that the same genus may include species some of which are freshwater, some brackish and some marine. But we need merely name the genera *Glœocapsa*, *Merismopœdia*, *Oscillatoria*, *Symploca*, and *Anabœna* as a few amongst others that are illustrative.

All of the above-mentioned details and others to be presently considered, strongly suggest that we have here to deal with a primitive, possibly *the most primitive* plant group now surviving. In further support of this, and at the same time opening up, as we believe, a highly suggestive line of investigation, is that morphologically diverse but physiologically similar series of the group, that may appropriately be called the "thermophile Schizophyceæ." This includes some 17 genera and 40–41 species which are found at the present day over the entire world, and inhabiting warm or even hot waters of geysers, hot springs, or warm mineral fountains.

When the suggestion was first made, now nearly a century ago, by a careful European botanist, that living algæ grew and flourished at a temperature of 55°–65° C., the record was viewed with suspicion or even contempt. Now we know that the estimate was understated for certain thermal species, and that a temperature of 70°–75° C. is by no means prejudicial for some. The subjoined list represents the genera and species that have been accurately determined, and which can so live and grow in water above the maximum for other plants, viz., 40°–45° C., that they may well be designated "thermophile species" (2, 3, 4).

Chroococcus thermophilus Wood.
Chroococcus varius A. Braun.
Synechocystis aquatilis Sauvageau.
Synechococcus æruginosus Naegeli.
Synechococcus curtus Setchell.
Glœocapsa montana Kützing.
Glœocapsa ? violacea Rabenh.
Glœocapsa thermalis Lemmerm.
Pleurocapsa caldaria Setchell.
Oscillatoria acuminata Gomont.
Oscillatoria sancta Kützing.
Oscillatoria boryana Bory.
Oscillatoria cortiana Menegh.
Oscillatoria geminata Menegh.
Oscillatoria okeni Agardh.
Oscillatoria grunowiana Gomont.
Oscillatoria terebriformis Agardh.
Oscillatoria chalybea Mertens.
Oscillatoria animalis Agardh.
Oscillatoria numidica Gomont.
Spirulina subtilissima Kützing.
Spirulina caldaria Tilden.
Phormidium treleasei Gomont.
Phormidium laminosum Gomont.
Phormidium angustissimum West.
Phormidium purpurascens Gomont.

Lyngbya nigra Agardh.
Lyngbya martensiana Menegh.
Aulosira thermalis West.
Symploca thermalis Gomont.
Inactis hawaiensis De Toni.
Plectonema nostocorum Bornet.
Hapalosiphon laminosus Hansgirg.
Hapalosiphon major Tilden.
Fischerella thermalis Gomont.
Dichothrix montana Tilden.
Dichothrix compacta Born. & Flah.
Dichothrix gypsophila Bornet.
Calothrix thermalis Hansgirg.
Calothrix kuntzei Richter.
Calothrix calida Richter.

In regard to these and other thermophilic organisms mentioned by him, a well-known biologist says: "no one doubts that in all the cases cited above, the individuals living in hot springs have been derived from ancestors which lived in water whose temperature rarely exceeded 40° C. The race has therefore become acclimatized, and the question arises: How has that acclimatization been effected?" The writer confesses to being one who would entirely reject the first statement, and who considers that while acclimatization of organisms is constantly proceeding, in the above group we have a primitive unacclimated series, from which cooler species have descended by acclimatization modification.

We would at once sum up our position by saying that we would regard these 41 species of thermophilic algæ as (1) persisting remnants of what was once a greatly more extended, continuous and abundant hot-water flora; (2) that they now live in waters richly charged with all the chemical ingredients—phosphorus at times excepted—needed for plant nutrition and growth; (3) that they are now forming extensive sinter or travertine deposits of siliceous or calcareous nature exactly like rock beds that can be traced back through the geologic formations to the mid-Archæan or Proterozoic rocks; (4) that the conditions under which they now live are probably—almost certainly—identical with those to which they have been exposed for untold ages; (5) that these conditions, though now restricted to limited areas of the earth (like the Yellowstone, Mammoth Spring, Sonoma and others in N. America, the Carlsbad in Bohemia, the Bormio, Lipari and others in Italy, those of Iceland, the Azores, Himalayas, New Zealand and Japan to mention only some of the best known) were once more prevalent, and during the Archæan epoch probably covered a large area of the earth's surface; (6) that in such warm waters, rich in chemical substances and in electro-chemical activities, we might well look for the first beginnings of life; (7) that these living thermophilic algæ are probably the surviving representatives of such anciently originating types; (8) that they, along with the thermophilic bacteria, suggest stages in the gradual evolution or devolution of elaborating phycocyanin, carotin and chlorophyllin pigments; (9) that the now more abundant species inhabiting cooler habitats, which are also exposed to less stimulating chemico-physical environment, are forms which have become cooled down with gradual cooling of the earth's crust, and with restricted exhibition of volcanic activity.

The above categories we will now shortly take up in succession. The *first* suggests that a more extended and abundant thermal flora once existed. When

we find, as in the case of *Phormidium laminosum, Hapalosiphon laminosus, Symploca thermalis* and others, that these occur over 3 or 4 continents of the Old and the New World in like situations, this is strong proof alike of a former more extended and abundant distribution as well as of their great antiquity. If such be true of forms that have come down to the present day, it is also strong evidence that, in earlier times when volcanic action was widespread, there would be a greater wealth of species, many of which have been exterminated in such extensive volcanic changes as occurred in the New Zealand hot spring region during a recent decade.

Second, the chemical composition of the waters in which the thermophilic algæ occur is exceptionally rich in dissolved inorganic compounds suited for their growth. Numerous detailed direct and also hypothetical analyses are given in Gooch and Whitfield's tables (5) for the leading western American thermal waters, and of these two of the latter need alone be given here from the Excelsior and the Splendid geysers:

Excelsior Geyser.			Splendid Geyser.		
Constituents.	Grams per Kilo of Water.	Per Cent. of Total Material in Solution.	Constituents.	Grams per Kilo of Water.	Per Cent. of Total Material in Solution.
NH_4Cl	Trace	Trace	NH_4Cl	0.0002	0.01
LiCl	0.0121	0.82	LiCl	0.0140	0.86
KCl	0.0821	4.22	KCl	0.0231	1.41
KBr	Trace	Trace	NaCl	0.4940	30.23
NaCl	0.3948	26.81	Na_2SO_4	0.0281	1.72
Na_2SO_4	0.0259	1.76	$Na_2B_4O_7$	0.0335	2.05
$Na_2B_4O_7$	0.0232	1.58	$NaAsO_2$	0.0025	0.15
$NaAsO_2$	0.0034	0.23	Na_2HPO_4	0.0002	0.01
Na_2HPO_4	Trace	———	Na_2CO_3	0.5286	32.36
Na_2CO_3	0.5739	38.97	$MgCO_3$	0.0018	0.11
$MgCO_3$	0.0077	0.52	$CaCO_3$	0.0075	0.46
$CaCO_3$	0.0055	0.37	$FeCO_3$	0.0001	0.01
$FeCO_3$	0.0037	0.25	Al_2O_3	0.0051	0.31
Al_2O_3	0.0023	0.15	SiO_2	0.2964	18.14
SiO_2	0.2214	15.04	CO_2	0.1989	12.17
CO_2	0.1365	9.28		1.6340	100.00
H_2S	Trace	Trace			
	1.4725	100.00			

We may compare these again with Sandberger's analysis of water from the Great Geyser of Iceland that gave in every 10,000 parts: silica 5.097, sodium carbonate 1.939, ammonium carbonate 0.083, sodium sulphate 1.07, potassium sulphate 0.475, magnesium sulphate 0.042, sodium chloride 2.521, sodium sulphide 0.088, carbon dioxide 0.557. The only element absent in the above analyses, that we now regard as important for plant nutrition is phosphorus. In connection with subsequent details the question might be ventured whether possibly sulphur can take the place of phosphorus in such a group as the Schizophyceæ. But in view of the possible proximity, in such thermal areas, of volcanic apatite rocks that might yield phosphatic compounds, the absence is rather noteworthy.

Third. The formation of siliceous and calcareous sinters and their relation to the Schizophyceous algæ may next be considered. The striking observations of Cohn (6) on the waters of Carlsbad, confirmed and extended by Weed (7) and subsequent workers, show that whether in siliceous or in calcareous thermal waters, definite species of the thermal algæ are so able to act chemically on dissolved constituents that the silica or the lime is precipitated in coarse colloid molecules or granules. These gradually unite with each other to produce agglutinated threads of gelatinous or colloid substance which collectively make up the sinter. "Upon the death of the algæ which have separated this jelly from the spring waters, there is a loss of a large part of its water, and a change to a soft cheesy, but more permanent form. This dehydration is carried still further if the silica be removed from the water and dried, but if allowed to remain in the cold water pools there is a further separation of silica, possibly due to organic acids, formed by the decaying vegetation reacting upon the silica salts of the water; this hardens the existing structures, in certain cases, and generally covers the pillars with a frost-like coating of silica. In general it may be stated that the large vase and pillar forms found in the algal pools can be produced only by the concurrent life and death of these plants, the outer layers continually growing, the inner dying. This is readily seen to be the cause of the peculiar structure of these forms. The central core is a pillar, sometimes hollow, sometimes solid, consisting of thin superimposed layers of silica, each of which corresponds with a layer of algal jelly, which has become hardened by the death of the plants and the loss of water. The column increases in diameter by the growth of the algæ at the surface, and a simultaneous death and hardening of the inner layer of jelly."

Over areas where the sinter is in process of deposition it is noticed, in the more celebrated geyser regions of the world, that a striking variation in color can usually be traced by the naked eye, and equally in the algæ when closely examined. The former give rise to those delicate but magnificent tints of color that have impressed every visitor to the regions in question; the latter shade from pale *Beggiatoa* forms that merge into elongated thread forms, through yellow to yellow-brown, pink, pinkish-green, purple-green, and—along the cooler margins of deposit—to deep emerald green. Reference will be made below to this color relation.

But no matter what the color species of alga be that precipitates the sinter, this soon loses its color and assumes a dull gray tint for siliceous, or a pure white hue for calcareous deposits. In regard to the after-relation of the algæ to the deposits Weed says: "The desiccation of such areas leaves a deposit of sinter whose surface shows no trace of its origin and of the beautiful forms beneath." This uniform opalescent character of the sinter deserves emphasis in connection with what we will state below as to the possible occurrence of rock masses similar in type and origin.

Fourth. In treating of the fourth question it will readily be accepted, we believe, that considerable though the area of hot spring activity now is, such is a

steadily diminishing amount compared with the areas occupied during more and more remote ages of the past. Weed says regarding the Yellowstone region: "There is perhaps no other district in the world where hydrothermal action is as prominent or as extensive as it is in the Yellowstone Park. In this area of about 3,500 square miles, over 3,600 hot springs and 100 geysers have been visited and their features noted, and there are also almost innumerable steam vents." But there are many geological evidences to prove that back to the time of the Cambrian and the Archæan or Proterozoic epochs such areas were evidently greatly more extended than now. There is no reason therefore to suppose that such simple algæ, carrying on the active rock-forming function that they do, were absent from the waters of such areas as the above, where an abundant food supply existed for them, that might be scant and hard to obtain elsewhere, either in cooler waters, on land, or in the sea. So we may well accept it as highly probable that some of these thermophilic algæ correspond, so to speak, to the Terebratulas and the Lingulas of the animal kingdom, in that they are very probably forms which have lived on through the ages, and through uniform environmental conditions, that represented their primitive environmental surroundings.

With increasing cooling of the earth's mass, derived species may have branched off from them that became modified to less stimulating or to chemically more restricted surroundings, and which would account for the numerous species of Schizophyceæ now living, some in fresh water, some on land, some in saline or in brackish regions, some by the seashore. If we bear in mind also the strongly mineral nature of the geyser waters, we need not wonder that such areas as Salt Lake show extensive beds of blue-green algæ like *Microcystis packardii;* that *Oscillatoria salinarum* can flourish in the escaped liquor from the salt works of Porto Rico, or that *Cœlosphæriopsis halophila* should live in a salt lagoon of the Hawaiian Islands. *Synechococcus curtus* again is said by its discoverer Gardner to have been found "floating in myriads in hot salt water, near Key Route power house, Oakland" (4).

Instead therefore of regarding the thermophilic algæ as acclimated species, there is equally good or even more abundant reason for considering, that they now inhabit surroundings which have remained little if at all altered from the period of their early evolution.

Fifth. Under this caption it might be observed that freshwater limestones, lime silicates and siliceous rocks, which often show few or no traces of organic remains, occur in most of the geological formations back to the Archæan epoch. At times they occur in a pure, at times in a more or less impure state. The thickness of the beds varies greatly from a few inches to many feet. Opinion was long divided as to their origin, but their probable vegetable formation is being more clearly emphasized. Thus speaking of the later Archæan or Proterozoic rocks Geikie (8) says: "these ancient stratified formations do not consist merely of clastic sediments. They include important masses of limestone and dolomite, sometimes highly crystalline, but elsewhere assuming much of the

aspect of ordinary gray compact Palæozoic limestone. Sometimes they contain a considerable amount of graphite, and some of the shales are highly carbonaceous. In other places they are banded with layers and seams or nodules of chert, in a manner closely similar to that in which the Carboniferous Limestone of western Europe contains its siliceous material. Sometimes the chert bands are as much as forty-five feet thick. The general character of these mingled carbonaceous, calcareous and siliceous masses at once reminds the observer of rocks which have undoubtedly been formed by the agency of organic life."

The beds also of opals, opal marbles and other siliceous compounds, also the marls and related carbonate rocks may in part at least have originated from the algæ of hot-spring activity. But even as temporary masses of colloid silicates and carbonates these sinters may often and widely have been deposited, to be again redissolved, or withered for formation of other sedimentary rocks. The evidence therefore seems fairly abundant and suggestive, that between the close of the igneous period, and before the deposition of Cambrian rocks, deposits were forming that can best be explained as due to the activity of plant organisms, and not least of Schizophyceous algæ.

Sixth. In approaching this topic it may be said that, during the past half century, biologists have tried to account for, or to trace the beginnings of life in still oceanic—even abyssmal—deposits or formations; in lagoons bordering the sea where varied inorganic compounds can accumulate to interact on each other; or again they have somewhat vaguely suggested the possibility of hot spring areas as active centers of molecular change. The last seems to the writer the only one that has much to be said in its favor.

We now recognize fully that organic bodies are fundamentally colloid aggregations. In hot springs colloid action and reaction are proceeding more actively and steadily than in any other region of the world. All organic bodies contain at least seven elements, which are either linked together in complex manner as colloid molecules, or they aid by contact action in building up and maintaining such molecules. As already noted, all of these elements except phosphorus exist side by side in loose states of combination and under high electro-chemical tension, in probably all of the hot springs of the world, though in siliceous springs like the Great Geyser, the silica predominates, in carbonate ones like the Mammoth geyser, lime predominates, while in the sulphur-bacterial springs to be treated of below, the element sulphur predominates.

The blue-green algæ and the thermophilic bacteria are formed fundamentally of a colloid pellicle that we may term mucilage-cellulose, and of enclosed protoplasm also of colloid nature, but of highly complex molecular composition. The latter excretes the former as a limiting osmosizing tension layer, much as does the enclosed substance in a Traube cell deposit the pellicle of diverse composition around it. More perfectly and on a larger scale in the post-igneous period of the world's history than at any later time, areas must have existed that closely simulated the hot springs of to-day, and where molecular colloid interactions

must have occurred on a large scale. There and then environmental conditions must have existed, that were eminently favorable for the upbuilding of complex colloidal bodies, and so there and then the remote and probably simpler ancestors of our existing thermophilic algæ may well have originated.

It should further be added that, while extensive areas of hot spring activity probably—almost certainly—existed, the geologist has advanced clearest evidences to show that in the mid or late Archæan epoch, lands of denudation, lagoon expanses, sea cliffs, and ocean areas were then established.

If we attempt with the physicist and geologist to estimate the time-limit that elapsed, say from the mid-Archæan to the close of that epoch, it is generally agreed that the period is a long one. Thus Haeckel, using the data of various geologists, considered that the Archæan and Cambrian rocks together averaged 63,000 ft. in thickness, and required about 52,000,000 of years for their formation, a length of time greater than that proposed by him for all of the later formations up to this date. Geikie has said "The geological evidence indicates an interval of probably not much less than 100,000,000 years, since the earliest forms of life appeared upon the earth, and the oldest stratified rocks began to be laid down."

Even if we limit the period from the mid-Archæan to the beginning of the Cambrian to 20,000,000 of years, the active changes proceeding then, as testified by the structure of the earth's crust, would be most efficient factors in evolving and modifying plant species. So an abundant hot spring flora of primitive type may slowly have originated and become distributed over wide regions during the mid and late Archæan or Proterozoic epoch, and from this may have evolved adaptive types of land, cool lake, lagoon, estuarine and sea dwellers.

This brings us to the consideration of evidence in favor of adaptation and modification of such thermophilic algæ from a warm to a gradually cooler environment. With the exception of thermophilic bacteria, that are discussed later, no other group of plants is capable of passing its entire life cycle at temperatures between 50°–75° C. Yet even at the present day there exist 40 or more such species of wide geographic distribution. A remarkable and unique feature of the Schizophyceæ, however, is that not only the genera, but even many of the species, are capable of flourishing under most diverse environmental conditions. In saying this the writer bears in mind that wrong specific identifications can readily be made in this group, since diagnostic descriptions are limited often to a few characters. But discounting a wide margin of possible error here, the statement just made seems eminently correct.

Thus the genus *Inactis* includes species that grow in freshwater ponds and there form calcareous pebbles, or that coat wet rocks or live in rushing cataracts, that grow in hot water or that cling epiphytically on marine algæ. Species of *Spirulina* may grow in brackish or salt marshes, in hot sulphur springs, on marine algæ, or in pools of fresh water. The single species *S. subtilissima* is recorded from thermal waters of Italy and Africa, from a salt creek in Nebraska, from a

sulphur spring in California, and in washings from marine algæ of Hawaii. Many similar records to these would suggest a plasticity and adaptive capacity at the present day that seem only possible of explanation as due to long continued exposure to altering environment. That so many freshwater and cool species have developed is probably due to geographic isolation and subsequent adaptation to a uniform and stable set of surroundings, in certain originally primitive types.

The writer graphically proved nearly two years ago that certain of them can resist great extremes of temperature, of drying and of insolation. For on a macadamized road leading from Morgarten to Schwyz, he watched, for two weeks, numerous examples of a nostocaceous species that grew from between the broken road metal. These shrank to small semi-leathery flecks when hot summer suns made the stones warmer than the hand could comfortably bear; they rapidly became swollen up when rain fell for an hour or two, while in winter they were exposed on the inclined road to temperatures greatly below that of the freezing point. A temperature range of 70°–75° C. seemed a concomitant of their annual life cycle.

Under the *eighth* heading, it would be impossible in the present paper to discuss at length the question of color variations as shown by the thermophilic algæ, and the possible relation of these to the important question of chlorophyll evolution. Suffice it if we here say, that from the physiological knowledge we now have of yellow, yellow-brown, yellow-red, purple-green, and blue-green schizophyceous pigments, it seems likely that we have here to deal with possibly one, perhaps two series of color compounds, that may all be capable of utilizing the sun's rays in the elaboration of synthetic plant foods.

Weed's graphic description therefore of the color gradations seen in many hot springs deserves quotation. He notes that as the water from a spring "flows along its channel it is rapidly chilled by contact with the air and by evaporation, and is soon cool enough to permit the growth of the more rudimentary forms which live at the highest temperature. These appear first in skeins of delicate white filaments which gradually change to a pale flesh-pink farther down stream. As the water becomes cooler this pink becomes deeper, and a bright orange, and closely adherent fuzzy growth, rarely filamentous, appears at the border of the stream, and finally replaces the first-mentioned forms. This merges into yellowish-green which shades into a rich emerald farther down, this being the common color of freshwater algæ."

The *ninth* line of inquiry has been already sufficiently touched on in the foregoing paragraphs, and need not detain us.

The second great group of the Protophyta is the Schizomycetes or Bacteria. Even more diverse views have been propounded, as to their cytology, than for the blue-green or schizophyceous series. We would regard them as being composed of a mucilage-cellulose or cellulose membrane, which in many of the more motile forms seems to be permeated by nitrogenous compounds. The protoplasm, as in the previous group, is rich, granular, and abundant; sap vacuoles are

small or appear to be absent in active cells; diverse food granules may be seen in the protoplasm; while in regard to a nucleus we would favor the view of most bacteriologists, that such is absent or only represented by minute chromatin granules ("chromidia" of authors) that may be loosely linked together in the substance of the protoplasm.

In studying the environmental relation of the group from the standpoint of protoplasmic adaptability, it may well be said that during the past 10 years few lines of experimental observation have produced so varied and suggestive results as those dealing with the thermophilic bacteria. Their presence in hot springs had been demonstrated almost a quarter century ago, but their existence in unlimited quantity in soils, in fermenting vegetable refuse, in manure, in the cloaca and alimentary canal of vertebrates, as well as on many living exposed plant parts, had not been suspected. As repeated experiment has shown, these thermo-bacteria are nearly all active at an optimum temperature of 55°–65° C., they are sluggishly—though sometimes actively—vegetating at 70°–75° C., while their spores can in most cases retain vitality at much higher temperatures.

But more than ordinary interest attaches, in our present inquiry, to the bacteria that flourish in siliceous, in calcareous, or in sulphur springs. Setchell (9) concluded after study of many western American localities, that "the chlorophylless Schizomycetes (or bacterial forms) endure the highest temperatures observed for living organisms, being abundant at 70°–71° C., and being found in some considerable quantity at 82° C. and at 89° C." He states also that in siliceous waters the limit of life for active bacteria is 89° C., but in calcareous waters the limit is 71° C.

About eight years before publication of Setchell's results, however, Karlinski (10) studied the waters of the hot sulphur springs of Ilidze in Bosnia. In the early part of his paper, he gives a table showing the composition of the water, and which the writer subjoins for comparison with those already given. One of the two springs that yield the supply has a temperature of 58° C., the other of 51° C.

Sulphate of potash	0.344	Bicarbonate of magnesia	4.547
Sulphate of soda	8.191	Bicarbonate of iron	0.077
Sulphate of strontium	0.030	Oxide of alumina	0.012
Borate of soda	0.053	Silica	0.485
Chloride of sodium	0.144	Hydrogen sulphide	0.039
Chloride of calcium	5.100	Free CO_2	4.496
Hyposulphite of calcium	0.019	Lithium, manganese, ammonia	traces
Phosphate of calcium	0.013	Organic substance	0.152
Bicarbonate of calcium	10.666	Insoluble constituents	24.990

He accordingly draws attention to the special abundance of sulphate of soda, of the two chlorides, of bicarbonate of lime, and of free CO_2. But in contrast to those already tabulated in this paper, the writer would emphasize the presence of iron and of phosphorus compounds.

In the Ilidze waters Zalinski found two thermophilic species. One was named *Bacterium ludwigii*, the optimum temperature for which was 55°–57° C.;

it continued to flourish even at 60°–70° C., and ceased growth only at 80° C. It was of a light yellow hue, and so contrasted with a snow-white form *B. ilidzensis capsulatus*, whose optimum was 59°–60° C., which still grew and multiplied at 60°–70° C., but could endure a higher temperature.

Miyoshi (11) found 9 types of bacterial organism in the thermal waters of Yumoto, at 51°–70° C. Of these 5 were red-colored, and 4 were colorless forms. Again Falcioni (12) found three varieties of what he identified as *Bacillus thermophilus* in the hot springs of Bullicame di Viterbo. If his identification is correct, this would be the same organism as Rabinowitsch and others have found in earth, manure, etc. Its optimum temperature was 60° C.

Georgevitsch (13) found in the sulphur springs of Vranje, a variety of the same bacillus which endured a temperature of 70° C. At 49°–50° C. it ceased to grow or multiply; its optimum was 56°–60° C. when spore-formation took place; at 68°–70° C. a reduction of vitality occurred. So for this as for several other thermophilic bacteria the minimum temperature is 48°–50° C., the optimum is about 58° C., and the maximum 70°–75° C. These results again are all similar to those of Benignetti for the hot waters of Acqui in Piedmont, and so it is probable that when world-wide studies have been made of the micro-organisms of sulphur waters a likely agreement of these will be noted, if the bacteria at all correspond to the blue-green algæ.

The literature on the thermophilic bacteria that inhabit soils, manure heaps and even the alimentary tract of animals is already extensive, but is admirably summarized by Ambroz up till a year ago (Central. für Bakt., 48 (1911), 257). These live in an optimum temperature of 55°–65° C., at 35°–40° C. they show minimum dormancy, at 70°–75° C. the maximum is reached. Their widespread abundance over probably the whole world, as Globig's tests would indicate, is one of the biological surprises of recent years, but is perfectly in keeping with the line of argument pursued in this paper.

Considerable diversity of opinion has been expressed as to their origin and biological significance. Below, the writer suggests a possible origin that may connect them equally with other bacteria that live in ordinary temperatures, and with the blue-green algæ. And in this connection the observation of Rabinowitsch (15) that of the eight types studied by her, the color varied from white through gray-yellow to brown, red and gray-green is really important.

Between the thermophilic bacteria and those which live at ordinary temperatures, all gradations have been studied. Thus *Micrococcus prodigiosus* has been proved to have a wide adaptability of temperature range, while Eisenberg's (16) recent experiments with *Bacillus anthracis* prove that it is active alike at normal temperature and up to 70° C.

If we review now the Schizomycetes as a whole, it seems to the writer entirely warrantable to conclude, that the most primitive group is that of the Thiobacteriaceæ or sulphur and iron precipitating species, which are partly thermophilic, and which alike in cell morphology and in formation of mineral deposits

are almost identical with many of the thermophilic Schizophyceæ. These again show every type of gradation in cell structure and in life cycle to the genera of the Leptothriceæ that are mainly saprophytic or parasitic. They again lead by *Streptothrix, Mycobacterium* and others to genera of the Spirilleæ on the one hand, and to the larger forms of *Bacillus* and *Bacterium* on the other. Whether the group of the Coccaceæ should be viewed as a direct offshoot from simple spherical Schizophyceæ, or as condensed and rounded derivatives from *Bacterium* is a question that need not concern us at present. The important announcement just made by Drew (17) "relates to the rôle of certain bacteria in depriving surface sea water of nitrogen and in precipitating the vast deposits of chalky mud (oolite) of the Florida-Bahama region." This is but another proof of the geologic activity of the Schizomycetes, though it is of immense value as carrying such activity into the ocean, and of possibly explaining to us the origin of the great marine chalk and lime beds of former epochs.

It is regrettable that our knowledge is still very limited as to the bacteria of siliceous and calcareous springs. But accepting their recognized occurrence there, and the great abundance of sulphur bacteria in hot sulphur springs, the conclusion seems fully warranted that hot-spring schizophytic organisms—alike in their schizophyceous and schizomycetous sections—were the primitive organisms of the world, and that amid all the environmental changes of denudation, upheaval, cooling, and more recent sharp action of such often severe environmental agents as hot suns, hot and cold winds, ice action, etc., some species have survived practically unaltered, from very ancient time amid primitive thermal waters, while hundreds of species derived from these have adapted themselves to a wide range of environmental habitat.

Naturally, we would regard the algoid or schizophyceous series as the primitive and main stock, since they are chemically autotrophic. The saprophytic and parasitic derivatives are in all likelihood offshoots from these. But it must here be borne in mind that though Winogradsky's and Molisch's views differ somewhat as to details of nutrition of the sulphur bacteria, these plants may indicate a capacity for autotrophic nutrition, or at least for chemical elaboration and energy-storage, that might give them a synthesizing dignity and independence apart from the Schizophyceæ.

For the Schizomycetes then, as for the Schizophyceæ, it is true that many species have become adapted to cool surroundings, and can even continue to grow and multiply at or below the freezing point. But it is as true for their spores as for the seeds of flowering plants, that after continued exposure to temperatures of $-70°$ C. to $-100°$ C. many still survive. So direct experimental and observational evidence both lead us to believe that rich and dense plant protoplasm had from earliest time an adaptive capacity up to at least 100° C., and also that it had or in time acquired a life-adaptation to $-100°$ C. or less. Such a wide range of temperature adaptability would aid many species to survive that otherwise would have succumbed.

One is tempted now to inquire as to the action of environmental light rays on both of the schizophytic groups. Unfortunately our knowledge is still so limited, that we can only speak with reasonable certainty along one line. Several sets of experiments, from those of Ward onward, demonstrate that when light passes a definite maximum of intensity it becomes injurious and even actively destructive. Thus in *Microbiology* (18) we read "most bacteria are killed by direct sunlight in a few hours," and "the different colors of the spectrum do not act alike; the part of the spectrum from red to green is practically without influence upon microorganisms, while the blue light acts strongest, and the intensity decreases in the violet and ultra-violet." This is exactly true of the higher nucleate plants, as first pointed out by the writer (19).

In proceeding now from the Protophyta or non-nucleate to the Metaphyta or nucleate plants, a noteworthy feature is that the cell or several cells that make up each mature organism, tend to become greatly vacuolated by absorption of relatively large supplies of water, while the chromatin that was absent, or present in a more or less "amphiplasmic" state becomes definitely aggregated into nuclear and nucleolar constituents. Possibly one, perhaps both of these changes may limit adaptability to diverse environmental conditions, and not least diverse temperatures, though the writer would lay greatest stress on water content. But when most metaphytic cells—the egg and sperm mainly excepted—become richly protoplasmic, or are protected by mucilaginous or pigmented cellulose or lignin coats, or pass by definite cyclic relation into a dormant resting state where the stored food and the granular protoplasm are relatively great in amount, and the nuclear chromatin is relatively small and surrounded by the former, a like wide range of protoplasmic adaptability to environment is witnessed.

Though greatly more extended and minute experiment and observation are needed, enough results have been secured to guide us. These we will treat of, in gradually ascending series, beginning with the algæ and fungi.

Alike because growing algoid cells are usually much vacuolated, and the resting spores have been little experimented with, our information as to algæ is still scant.

According to the temperature records given by West (20) for the material collected by A. W. Hill at hot springs in Iceland, not only blue-green algæ but numerous species of diatom, three species of the Desmid *Cosmarium* and even a species of *Zygnema* live at temperatures of 49° to 61° C., thus apparently confirming Berggren's and Börgesen's accounts for New Zealand and Iceland. A more careful study of such higher algæ in relation to environment is greatly to be desired however. But amongst fungi we know that yeasts such as *S. cerevisiæ* and *S. hansenii* can live after several days' exposure to −70°–100° C., though vegetative activity starts about 10° C. From the latter temperature upward, yeast continues to bud in nutritive solution, according to A. Meyer, up to 53° C., while air dried yeast remains alive up to 100° or 110° C. The *duration* of life, at optimum temperature, of pressed yeast is stated by Claude Bernard and Schumacher to continue for two years.

Pasteur found that the dry conidiospores of *Penicillium glaucum* could endure a temperature of 108° C., but that in liquid they were killed at 100° C. The dry spores of species of Smut (*Ustilago*) survive heating to 104°–120° C., but when moist are killed at a temperature of 60°–73° C. Chodat (20) exposed spores of *Mucor mucedo* to a temperature of −70° to −110° C., and even considered that the mycelium may be equally frozen. He concludes that "la vie est conditionnée par certaines structures. Les forces qui les mettent en jeu peuvent etre des forces toutes physiques. Elles sont simplement les sources d'énergie qui pourront mettre la machine en mouvement."

But the behavior of many lichens in the vegetative state is highly instructive, compounded as they are of a fungoid and of a schizophyceous algal constituent. Growing on bare open rocks, they may be exposed for a few hours or days to rain, and then for weeks or months mayhap to broiling suns. Along the French Riviera coast in July the writer has placed his hand alongside some of these as they grew on the red rock, and had speedily to withdraw it again as a matter of comfort. Kerner (22) says regarding them: "The crustaceous lichens adhering to the limestone rocks of the wild regions of the Karst of Istria and Dalmatia (*Aspicilia calcarea, Verrucaria purpurascens*, and *V. calciseda*) are regularly exposed on cloudless summer days to a temperature of 58° to 60° without injury, and the edible lichen (*Lecanora esculenta*), is often heated in the deserts, along with the stone on which it grows, to fully 70°, and yet is not destroyed."

Few exact records have been published for the mosses, and a promising field for inquiry is here open. But the recent studies of Irmischer (31) suggest future extended observations that will yield important results.

While ferns are as a group umbrophilic plants, it can equally truly be said that species of *Pellæa—e. g., P. atropurpurea—Notholæna*, and some epiphytic tropical species of *Polypodium* are truly thermophilic. The leaves of such species are often smooth and leathery; they contain a relatively small amount of moisture even after rain; they grow on exposed gray-white rock faces, or epiphytically on dry tree trunks; they may remain shrivelled and apparently dead for weeks or even months without moisture other than dew; at times even hot dry winds accentuate the often intense insolation. Yet they live unharmed at temperatures which may run from 65°–70° C.

On the hot white sandy knolls over the savannahs near Wilmington, N. C., *Selaginella acanthonota* has its hard wiry patches of branches exposed for weeks to direct day temperatures of 60°–65° C., while its near ally the well-known resurrection plant of California and Mexico (*Selaginella lepidophylla*) can not only endure such heats, but will live for months out of the ground in a box, and if again planted will unfold its shoots, revive and grow.

In all of the above sun-exposed plants, it is evident that—no matter what view we may hold as to the function of cuticle and epidermis in relation to subjacent cells—the epidermal cells at least were exposed to all of the constituent rays of an intense light.

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If attention be now turned to the spermatophytes or flowering plants, evidence that has accumulated during the past quarter century entirely favors the view, that many plants or plant parts are adapted to much more diverse environmental relations than we formerly inclined to grant. Since the successful endurance by seeds of diverse environmental changes is an important feature in the perpetuation of species, we may begin our study with them.

Quoting from the passage already referred to from Kerner he says: "Seeds which are deposited on the desert sands, and survive in this position long periods of drought, do certainly assume the temperature of their environment, and although at noon this often amounts to 60°–70°, it does not injure these seeds: since when the rainy season returns, they are roused from their summer sleep and germinate in the cool and moistened soil. The highest temperature in the superficial layer of soil has been observed near the equator at Chinchoxo on the Loango coast. Here, in many cases it exceeds 75°, often attains 80°, and once attained to even 84.6°. Nor is this soil destitute of annuals during the rainy season, and without doubt the dry seeds of these plants have been lying for months in the sand, sometimes heated to over 80°, without losing their germinating power."

Of various seeds also which had been deprived of a safe amount of water, he states that they can be heated for 3 hours to 100° C., and yet the greater number may germinate. We can scarcely doubt that every living cell in the seeds was as fully exposed to a temperature of at least 70°–75° C. as were the schizophyceous algæ of the hot springs. Even more remarkable were the results secured by Brown and Escombe (23), also by Thiselton Dyer (24) as to protoplasmic adaptability of seeds to extremely low temperatures. The former experimenters selected 12 kinds of seed taken from eight different families, some of which were albuminous, and some exalbuminous. The seeds were air-dried and so contained about 10 to 12 per cent. of natural moisture. After being slowly cooled they were immersed in a flask of liquid air, and exposed to a temperature of −183° to −192° C. for 110 hours. But on removal they showed as good germinating capacity as did control seeds.

In Dyer's experiments six kinds of seeds from five families were used, and their germinating capacity was tested by sets of control seeds. Some were exposed in liquid hydrogen to a temperature of −250° C. for an hour; others were similarly exposed for six hours, while a third set was exposed to liquid air. All germinated as perfectly as would any good seed sample, and as did the control seeds. Such experiments not only confirmed the earlier results secured by C. de Candolle and Pictet, they strengthened Pictet's conclusion (25) that "since all chemical action is annihilated at −100° C., life must be a manifestation of natural laws of the same type as gravitation."

De Candolle's (26) added experiment of placing seeds in the snow-box of a refrigerating machine at −37° to −53° C., for 118 days leads us to note the extreme vitality of some seeds. We now have sufficient verified proof to accept it that

some malvaceous and particularly some leguminous seeds, remain in a state of "dormant vitality" for a period of 5 to 50 years at least. That they are living and not dead bodies during all of this period, is shown by their being germinable at any time; by their undergoing a slow but gradual loss in germinating capacity; and that a stage is ultimately reached when life-changes can no longer be started; that is, the irritability of the cells in the albumen and in the embryo, which may have persisted for many years, fails longer to express itself.

Waller (27) in his electrical blaze-response experiments failed to obtain any evidence of life in such dormant seeds, and felt that he was accordingly placed in a dilemma. He in part tried to escape from it by saying that "it is possible—or rather, certain—firstly that our means of chemical investigation are not refined enough to reveal to us the smallest and most infinitesimal changes that may be going on in an apparently dry and perfectly dormant seed; and second it is possible that chemical change may be completely and absolutely arrested (*e. g.*, by low temperature) without that arrest being of necessity final and definite."

Without at present going further into the subject, we would merely state the fact that under definite environmental states some seeds contain cell protoplasm—probably mainly in the embryo—that retains its irritable and chemico-physiological capacity for response through a period of at least half a century, though in a so greatly reduced state of activity that galvanometric records seem to be feeble or unobtainable.

Before leaving this subject, reference may be made to the peculiar results obtained by Romanes (28) with seeds that were exposed in highly exhausted vacuum tubes for 15 months; or for three months, and thereafter transferred to tubes charged at air pressure with gases or vapors of hydrogen, carbon monoxide, carbon disulphide, ether, etc., for an added period of twelve months. His result was "that neither a vacuum of $\frac{1}{1,000,000}$ of an atmosphere, nor the atmosphere of any of the gases and vapors named in the above list, exercised much, if any, effect on the germinating power of any of these seeds." Dyer in the article already quoted states on the authority of another without giving any evidence, that "an injurious effect is ultimately produced." But even granting such, to have secured germination is proof that protoplasm may behave with great endurance to environmental agents.

In view of statements that have usually been current in the past, as to protoplasmic adaptability and resistance, it might scarcely seem likely that the cells of any vegetative part of a flowering plant could endure a temperature higher than 42°–45° C. And while this may be true for each plant in some one or other of its tissues, if we can show that certain living tissues can be exposed to 60°–70° C., and to direct insolation that roughly corresponds in intensity to this temperature record, or again to temperatures as low as $-60°$ C. for hours of each day, then we have gained a clearer insight into the adaptive capacity of cell protoplasm, seeing that all the cells of any flowering plant are derived from the fertilized egg-cell.

Over the hot desertic expanses of the Chihuahuan area in N. America, the Sahara and the Karroo of Africa, or the interior plains of Australia, groups of plants belonging to quite distinct families grow, and sometimes even attain to great stature, under temperature and light conditions that might seem impossible. Thus the yucca, the agave, the cactoid and the xerophitic leguminous groups of the Chihuahuan areas; the grape-vines, the geranioids, the stapelias and the aloes of Africa; the proteads, eucalyptoids, the verticordias and other Myrtaceæ, also the Leguminosæ of Australia are exposed in their leaves or in their shortened stems to an intensity of temperature that must often register 60° to 65° C., and which must be fully felt in the epidermal cells at least of the more succulent types; and throughout the tissues generally in the many dry leathery ones of these regions.

The behavior of the Californian plant *Lewisia rediviva* alone is instructive. In the *Botanical Magazine* it is said that the specimen there figured from Kew was "one of many which, when gathered with a view of being preserved for the herbarium, in British Columbia, by Dr. Lyall, R. N., of the Boundary Expedition, was immersed in boiling water, on account of its well-known tenacity of life. More than one and a half years after, it, notwithstanding, showed symptoms of vitality, and produced its flowers in great perfection in May of the present year, in the Royal Gardens of Kew."

Kerner (22a) and Schimper (29) have both cited cases where, over extensive areas the heat, the cold, and the light influence must all be pronounced. The former cites Chinchoxo on the Loango coast where the soil layer may be 75°–85° C., and Yakutsk in Siberia where − 62° and − 63.2° C. (the lowest temperature hitherto generally observed on the earth) were noticed. There for months the temperature in the shade does not rise above − 30°, but numerous herbs and shrubs are found whose upper organs are exposed for weeks to a degree of cold at which mercury freezes."

But it must equally be emphasized that many plant species have a definite physiological minimum and maximum, during the vegetative period, that may lie between comparatively narrow limits of temperature. Thus the writer (30) has shown not only that related species of *Crocosma* may live or die as they are exposed to slightly different degrees of cold, but that the hybrid between these may show a fairly exact mean between the two. He has also stated that a like condition holds for *Philesia*, *Lapageria* and their hybrid. Even the units of heat needed to bring hybrids into bloom seem to be—from the writer's studies that have been extended by others since—fairly intermediate in amount between those needed for the parents, if these bloom at different dates.

In summary it might be said that if plant protoplasm shows an adaptability even in spore cells and seeds from 85° C. to 100° C. over long periods, and also to temperatures from − 100° to − 250° C., those cases where it shows a less degree of adaptability probably represent an acquired condition, in which, owing to absorption of extra water by the protoplasm, it is thereby rendered more un-

stable. Setchell well remarks in the paper already quoted: "We find that when a proteid, like egg albumen, is free from water, it does not coagulate at the very highest temperatures which leave it unburned, and that the less the content of water, the higher the temperature of coagulation." The most resistant plant parts are undoubtedly those in which abundant protoplasm, with or without stored protein or other food stuffs, fairly well fills the cell. Such cells or cell aggregations show a wide range of biological possibilities in relation to environment.

The views set forth above may be summarized as follows:

1. Plant protoplasm may show a degree of temperature adaptability that may range at least from $-200°$ C to $+100°$ C.

2. The most ancient, and in structure most primitive plants are probably the Schizophyceæ (Cyanophyceæ), which may have originated during the Mid Archæan or Proterozoic epoch, and were probably active agents then, as now, in forming the siliceous and calcareous beds encountered in the strata of that period.

3. The representatives of that group now living in hot springs and thermal waters, seem to be direct or little altered derivative species from the ancient or Archæan types, and no good reasons can be advanced for viewing them as adaptive or acclimated from more cool and temperate species.

4. They, like all thermo-resistant plant structures, have a rich and relatively dense protoplasm, or a stored mass of reserve material with it in the cells, that contribute to their thermo-resistant qualities.

5. The above qualities are aided when mucilaginous walls or cell contents, or thick and pigmented cellulose or ligin or cuticularized walls, exist in the above group, or in any division of the higher plants, since these act as insulators and equilibrators against over-rapid environmental action.

6. That the thermophilic bacteria also represent an ancient series, either derived from the Schizophyceæ by disappearance of the synthesizing cell pigments, or arising independently by utilization of energy from sulphur or siliceous compounds. These like the Schizophyceæ have been active in the formation of extensive rock masses of a sulphurous or ferruginous kind.

7. That from the almost assuredly verified deposit of extensive siliceous, calcareous, sulphur and iron rocks by one of the above two groups in late Archæan times and on to the present day, we have strong suggestion that the Schizophyceæ and Schizomycetes represent primeval groups whose rock-forming activities have been and are shown, where surroundings are favorable.

8. That all physico-chemical, geological and biological knowledge point to the conclusion that thermal spring action was once greatly more extended than now, but that the restricted areas which now show it do not seem to differ in their relations, their deposits, and probably in their organisms, from those of ancient geologic origin.

9. That the molecular composition, chemical activities, high energizing

temperatures, and abundant colloid substances, evidently existent in primitive thermal waters, all favored formation of abundant colloid compounds from simpler constituents, and this on the principle probably of Traube's cells.

10. That the living Schizophyceæ and Schizomycetes show graded advance in cell morphology from simple spherical unicellular and asexual organisms devoid of any recognizable chromatin or nucleus, to thread forms in which chromatin granules or loops are aggregating into a nuclear structure.

11. That protoplasm, as claimed by Pictet, Loeb, and Chodat is a chemical compound "that conforms to the same fundamental laws as do inorganic bodies," but which exhibits a greatly more complex structure and capacity of adaptation and response to environal stimuli, owing to the greatly more complex combination of the organizing molecules.

12. That the Schizophyceæ of thermal springs show varying degrees of coloration of their cells, which suggest graded stages in chlorophyll evolution.

13. That the Schizomycetes originated as a later offshoot from the Schizophyceæ, or as a primitively independent colorless group that utilized chemical energy from siliceous, calcareous, sulphur or other compounds. From this group saprophytic and parasitic forms arose, that developed corresponding habits.

14. That during gradual cooling of the earth, and restriction of volcanic and hot spring activities, thermophilic organisms became adapted to more temperate surroundings, and gave rise by adaptive modification to more recent plants.

15. That throughout the entire vegetable kingdom, at some stage in the life history of many plants, a wide ancestral adaptive capacity is shown by the cell protoplasm to temperature, light and chemical agents.

16. That not merely spores and seeds, but many other parts—even entire plants—of the Spermatophyta, show a wide range of environal relation, that is in no way different from that shown by the simple thermophilic organisms.

17. That relative water content is probably the main determining agent in conferring varying degrees of response on all plants or plant parts, though this is probably correlated with the presence of varying coagulable proteids.

18. That possibly the relation of the chromatin in the Metaphyta, to the protoplasm and to water content, have also an important bearing on species adaptability.

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THE RELATION OF PLANT PROTOPLASM TO ITS ENVIRONMENT

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